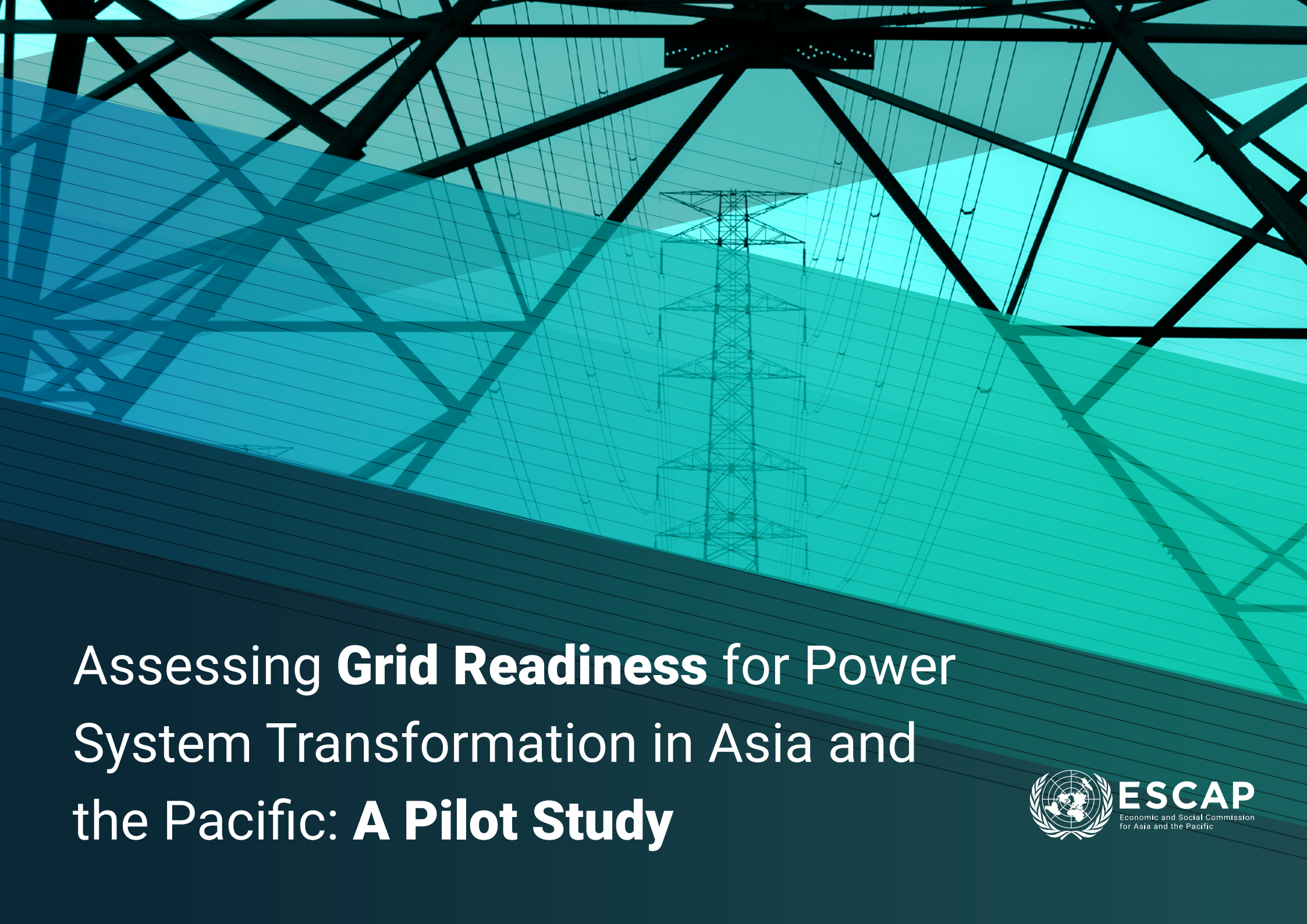

Assessing **Grid Readiness** for Power System Transformation in Asia and the Pacific: **A Pilot Study**

ESCAP
Economic and Social Commission for Asia and the Pacific

*The shaded areas of the map indicate ESCAP members and associate members.**

The Economic and Social Commission for Asia and the Pacific (ESCAP) is the most inclusive intergovernmental platform in the Asia-Pacific region. The Commission promotes cooperation among its 53 member States and 9 associate members in pursuit of solutions to sustainable development challenges. ESCAP is one of the five regional commissions of the United Nations.

The ESCAP secretariat supports inclusive, resilient and sustainable development in the region by generating action-oriented knowledge, and by providing technical assistance and capacity-building services in support of national development objectives, regional agreements and the implementation of the 2030 Agenda for Sustainable Development.

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Abbreviations

AEMO	Australian Energy Market Operator
ASEAN	Association of Southeast Asian Nations
CASA-1000	Central Asia South Asia Electricity Transmission and Trade Project
COP	Conference of the Parties
EGAT	Electricity Generating Authority of Thailand
EMA	Energy Market Authority (Singapore)
GW	Gigawatts
Hz	Hertz
IEA	International Energy Agency
IPP	Independent Power Producer
kV	Kilovolts
MVA	Megavolt Amperes
MW	Megawatts
PDP	Power Development Plan
PLN	Perusahaan Listrik Negara (State Electricity Company of Indonesia)
RE	Renewable Energy
RUPTL	Rencana Umum Penyediaan Tenaga Listrik (Indonesia's National Electricity Supply Business Plan)
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TWh	Terawatt Hours
VRE	Variable Renewable Energy

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1. Introduction

The modernization and expansion of electricity grids are key to achieving global energy transitions. Outdated and underdeveloped grid infrastructure, however, remains a major bottleneck to the large-scale deployment and integration of variable renewable energy (VRE), slowing down progress toward clean and secure energy systems. This study provides a starting point and pilots a methodology for the ongoing assessment of the readiness of national grids to enable clean energy transitions in the Asia-Pacific region, and serves as a companion piece for similar studies undertaken for Africa and Latin America. It aims to guide policymakers, financial institutions, and industry representatives through the initial development of a structured assessment framework that can be used, as the work evolves, to track the status of grid development within key countries, thus supporting informed decision-making across these stakeholder audiences.

For policymakers, a clear understanding of grid infrastructure and the readiness of power systems to integrate higher shares of VRE is vital for designing effective power system policy and regulatory frameworks, setting sectoral priorities, and ensuring long-term energy security. Strengthening electricity grids is not only essential for meeting climate targets but also for enhancing energy resilience and economic stability. This study provides an initial assessment framework that enables governments to identify gaps in the building blocks for progress on national energy transitions.

Investors and financial institutions require reliable data to assess risks and opportunities for investment in grids. The findings of this study will help to identify priorities for development to enhance grid resilience and enable renewable energy integration. By establishing clear indicators and methodologies for evaluating grid performance, it aims to support financial institutions in making informed investment decisions that align with long-term sustainability goals, highlighting the need for rapidly expanded grid investment, and ensuring that financial resources are allocated effectively to accelerate the transition.

For the power industry, including utilities, grid operators, and technology providers, this study offers insights into the current state of grid infrastructure and future development needs. A well-functioning grid is essential for integrating new renewable projects, optimizing energy distribution, and maintaining system stability. The study's findings can guide industry players in developing, prioritizing and deploying key grid-related solutions, enhancing grid management, and collaborating with policymakers and investors to scale up clean energy deployment.

By addressing the needs of different stakeholders, this study seeks to contribute to building resilient grid networks that can withstand challenges related to power system decarbonization, and adapt to power systems with renewable energy at their heart.

Background

The global energy transition is a critical objective aimed at mitigating climate change and achieving sustainable development. Central to this transition is the expansion and modernization of electricity transmission and distribution grids, which serve as the backbone for integrating VRE into power supplies.

At COP28, over 120 parties signed the Global Renewables and Energy Efficiency Pledge, which aims to triple renewable energy capacity and double the global average annual rate of energy efficiency improvements by 2030.[1] Achieving these ambitious targets requires the development of existing power grid infrastructure to accommodate rapidly increasing shares of VRE such as solar and wind energy. Current projections estimate that global renewable energy capacity will need to increase from 3,870 gigawatts (GW) in 2023 to at least 11,000 GW by 2030.[2]

However, despite these ambitious goals, transmission and distribution networks are creating bottlenecks to progress, delaying the timely delivery of VRE at scale, and causing connection issues for new generation projects. Building resilient and efficient grid systems at a faster pace is thus required to accelerate renewable energy deployment. According to the International Energy Agency (IEA), electricity transmission and distribution grids will need to expand by 2 million kilometers per year by 2030 for countries to be on track to achieve net-zero emissions targets. Reaching this target would require a doubling of grid investments to USD680 billion per annum by 2030.[3]

Recognizing the importance of grid infrastructure and energy storage in the energy transition, the COP29 Presidency introduced the Global Energy Storage and Grids Pledge, which calls for countries to modernize and expand electricity grids to support the transition to clean energy, and includes a target to upgrade over 80 million kilometers of power grids by 2040 to integrate VRE and improve system resilience. The Pledge also aims to increase global energy storage capacity by six times by 2030, enhancing the reliability of VRE-centric systems and allowing for the most efficient use of renewable power sources.[4] Since COP29, 65 countries (among over 100 total signatories) have signed on to the Pledge.

The Asia-Pacific region has one of the most diverse electricity grid systems in the world, ranging from highly advanced networks in countries like Australia, Japan, the Republic of Korea and Singapore to developing and fragmented grids in parts of South-East Asia and Central Asia. While some countries have well-integrated, reliable power transmission networks, others face challenges including grid congestion, infrastructure which is no longer fit for purpose, and limited cross-border connectivity. At COP29, 20 Asia-Pacific nations, including Australia, Cambodia, Japan, Kazakhstan, Republic of Korea, Singapore, and

1 https://www.iea.org/reports/cop28-tripling-renewable-capacity-pledge
2 https://www.iea.org/reports/renewables-2023
3 https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach/executive-summary
4 https://cop29.az/en/pages/cop29-global-energy-storage-and-grids-pledge

Tajikistan, endorsed the Global Energy Storage and Grids Pledge, signaling their commitment to enhancing grid development as a key enabler of power system decarbonization.

For example, in addition to ambitious domestic grids targets, Australia announced a USD125 million investment aimed at facilitating grid development in Pacific nations.[5] Kazakhstan reaffirmed its commitment to achieving carbon neutrality by 2060, seeking to supply 50 per cent of its power with renewable energy by 2050, including through a focus on grid modernization.

The commitments made through the COP29 Global Energy Storage and Grids Pledge demonstrate the growing global recognition of the essential role that robust grid infrastructure and energy storage play in the transition to a sustainable energy future. While countries in the Asia-Pacic region face different grid-related challenges and starting points, the Pledge provides an initial framework for accelerating grid development, enhancing regional cooperation, and integrating more renewable energy into the system.

Achieving these targets will require coordinated efforts among a range of relevant stakeholders to build resilient and efficient power systems capable of supporting the rapid expansion of renewable energy in the Asia-Pacific region and globally. Indeed, in this sense, the Pledge itself should be seen a starting point for national and international action on grid development. What is required now is concrete action, chiefly at the country level, to put in place formal national commitments and clear policy and investment frameworks that can result in the achievement of the objectives set out in the Pledge. This study aims to provide a baseline or snapshot of the current status of grids in selected countries across the Asia-Pacific as a benchmark for assessing this practical progress over time.

Scope of the study

In an effort to provide an in-time snapshot of this kind, and thus to raise awareness and build consensus on the multi-dimensional needs associated with strengthening power grids, this report provides a summary of an extensive data collection and analytical process that has been undertaken to understand the status of grids in the Asia-Pacific region. It is designed as a pilot phase on which future work can be built, focusing on the development of an initial framework to assess the status of grids, identifying critical indicators for this assessment, highlighting and seeking to address key data gaps, and testing a pilot methodology in this regard. Insights from this pilot will help to refine methodologies that can be used in the future, improving indicator selection and categorization, and ultimately incorporating stakeholder perspectives.

As well as setting out a new methodology, and its component parts, the report contains initial data and assessment for selected countries in Asia and the Pacific, using economic, institutional, environmental, social, and technical indicators, primarily based on publicly available, open-source data.

5 https://www.foreignminister.gov.au/minister/penny-wong/media-release/125-million-support-pacifics-renewable-energy-transition

2. Methodology

Key methodological principles

The primary aim of the current analytical exercise is to develop a methodology and conceptual framework that is consistent, easily scalable, adjustable and replicable across different countries and regions, and over time, in order to track the status and development of countries' grids, in particular with reference to their ability to integrate growing shares of VRE.

It serves as a pilot or proof-of-concept that tests data availability, the robustness of key indicators for grid health and readiness, and the consistency and replicability of the methodology under consideration across countries with diverse contexts and starting points, including in different regions, although this report covers the Asia-Pacific only. The exercise focuses on large-scale data collection at the country level, mainly using macro-level, publicly available and open-source data, with a key aim to test data availability and assess existing gaps.

The data gathering process and analysis undertaken only provides an overview of general macro-level conditions related to the country's power grid, which needs to be complemented by deeper analysis of policy and regulatory frameworks and by detailed country-level technical exercises assessing power flows in grids and networks that identify weak spots and expansion and upgrade requirements, including priority projects, vis-a-vis future demand projections.

It also focuses largely on high-voltage transmission networks (which are defined somewhat differently across countries), given the importance of this sector to renewables integration. This means that analysis of distribution networks will require further and additional examination.

Finally, although importantly, the current assessment also does not aim to compare, rank or score countries, given their diverse contexts and economic starting points, but instead seeks to provide a baseline understanding of each country's current strengths, weaknesses and challenges relating to grid development and VRE integration, therefore allowing progress to be tracked over time.

Indicators for grid readiness

An extensive list (more than 50) of grid-related indicators was compiled across five categories: status of power sector transitions, grid development, grid operation, distribution and demand-side/consumer considerations. Data was then gathered against this list as a first step. Based on initial analysis and data collection, this list was synthesized into a focused set of Key Indicators, intended to represent the most critical considerations for assessment of grid readiness in a given country, noting that these were deliberately tailored for the Asia-Pacific context, and with the proviso that countries with different energy resources will likely approach energy transitions in diverse ways. The Key Indicators are set out in Section 3, and presented with country data in Section 6. The development of indicators was designed to be flexible, and with the following tenets in mind:

- Scalability: the number of indicators in each category can be easily expanded or made more focused based on the use-case, although this will be subject to data availability.
- Adjustability: the choice of indicators can be adjusted to diverse country and regional contexts, considering data availability, data definitions and methodology, and appropriateness to country and region-specific conditions.
- Replicability: utilizing consistent assessment criteria and multi-year country data from both international and national sources was designed to make the current exercise replicable across countries and over time.

Data and information sources

One of the objectives of this pilot project is to test the usability and usefulness of macro-level and publicly available open-source data. The analysis principally relied on the following:

- Multi-country, multi-year, macro-level databases published by international organizations, national and regional organizations, academia, and other credible non-profit or private sector organizations.
- Documents and data published by national governments.
- Reports, documents and online information published by international organizations, regional organizations, academia, and other credible non-profit or private sector organizations for the power sector and network sub-sector analysis.

The current exercise employs both quantitative and qualitative data. While quantitative data is clearly critical, qualitative data and information – included in, for example, energy and climate policies, grid system planning framework and procedures, economic regulations and tariff setting methodologies etc. - are equally important for understanding grid readiness among countries.

3. Key Indicators

Table 1 below provides the list of Key Indicators that were identified to map grid readiness, with an explanation for each.

Table 1: List of Key Indicators for Grid Readiness

Power Sector Transition	Share of RE in power generation (%)	Percentage of all non-thermal generation in total generation mix, in terawatt hours (TWh)
	Share of VRE in power generation (%)	Percentage of variable solar and wind generation in generation mix, in TWh
	Annual growth in VRE penetration (5-year average)	Illustrates historical growth trend in solar and wind penetration over the past five years
	VRE in grid connection queue	Details the amount of VRE currently waiting for connection to grids, in megawatts (MW)
	Annual growth in power demand (5-year average)	Presents historical national demand growth trend over the past five years
	2030 demand projection vs generation supply target	Demonstrates potential gap between supply aspirations and projected demand growth by 2030, in TWh
	Independent regulatory body (Y/N)	Is the power sector regulated by an independent regulatory authority?
Grid Development	Transmission system capacity	Snapshot of the current capacity of the transmission system measured in Megavolt Amperes (MVA)
	Transmission circuit length	Snapshot of the current size of the transmission system measured in kilometres
	Annual growth in transmission expansion (5-year average)	Illustrates historical growth trend, if any, in transmission system development over the past five years
	Private participation in grid development (Y/N)	Does the country in question allow private sector investment in grid asset development?
	Interconnections with neighbouring countries (Y/N)	Does the country in question have interconnections across borders with neighbouring countries
	Current interconnections capacity	Presents the size of cross-border trade through interconnection, in MW
Grid Operation	Grid losses	Percentage of power passing through transmission system that is lost in this process
	% RE curtailment	Average historical percentage of renewable generation that is not utilized for operational reasons
	VRE priority dispatch (Y/N)	Does the country or jurisdiction have operational requirements to prioritise dispatch of VRE generation
	Economic grid tariff determination (Y/N)	Is transmission pricing/cost recovery set economically or administratively?
	System flexibility index	Presents the level of flexibility in the power system based on international indices
Consumer/ demand-side	Electricity access	Percentage of total population with access to reliable electricity
	SAIDI/SAIFI	Measures system reliability (System Average Interruption Duration/Frequency Indices)
	Cost-reflective tariffs (Y/N)	Do end-users (households, industry etc.) pay subsidized prices for power?
	Environmental impact assessment (Y/N)	Do countries have processes to determine environmental and social impacts of grid projects?
	Public consultation (Y/N)	Do countries have public consultation mechanisms in development of grid projects?
Distribution	Distribution network capacity	Snapshot of the current capacity of the distribution system measured in MVA
	Distribution network length	Snapshot of the current size of the distribution system measured in kilometres
	Annual growth in distribution expansion (5-year average)	Illustrates historical growth trend, if any, in distribution system development over the past five years
	Distribution sector losses	Percentage of power passing through distribution system that is lost in this process

4. Key Learnings and Areas for Further Analysis

As a pilot or proof-of-concept, a key aim of the current analytical exercise was to identify learnings and areas for further work and concept improvement to inform efforts tracking grid readiness in the future. A number of lessons can be drawn from the process.

Firstly, it is possible to develop a simple framework for assessing grid readiness that can be broadly applied. The same process and methodology set out in this report was also used with similar results for Africa, and even within the regions of Asia and Africa, diverse countries were examined with the same approach. The simple methodology that was applied, however, is designed to be flexible, and would likely need to be somewhat amended (i.e., by adding and removing Key Indicators) for regions, for example Europe, with generally higher levels of development than Asia or Africa.

While the assessment framework is broadly applicable, it is clear that it is problematic to compare countries to one another using the same metrics and indicators. Even within regions, countries have fundamentally different socio-economic contexts and starting points, geographies and access to domestic energy resources, renewable or otherwise. A direct and simple comparison or ranking of countries would not fairly acknowledge these differences. Instead, as discussed, this exercise aims to provide a baseline understanding of each country's current strengths, weaknesses and challenges relating to grid development and VRE integration, which can be tracked over time.

The current exercise demonstrated that there is a wealth of publicly available, open-source data on grids that already exists. A significant majority of data that was sought was ultimately found. Data tended to come from a countless array of national and international sources, however, suggesting that continued efforts to bring key data on grids together would be of use – this pilot has sought to begin this process. In this regard, multi-country databases that currently exist, published chiefly by international organizations, were particularly useful.

Having said that, significant data gaps still exist. Indeed, some of the most important and granular data was often most difficult to obtain. Data on curtailment rates, VRE projects in connection queues, average project timelines and project costs, for example – each critical to assessing grid readiness – were largely missing. Efforts to fill these gaps, potentially through a deeper process that includes consultation with national stakeholders, would be useful. Data on the distribution sector was more difficult to obtain than that on transmission, suggesting this as an area of future focused analysis. Data quality was also an issue, with frequent discrepancies arising between different publicly available sources (for example, national data vs. international benchmarks).

While the current exercise provides a good high-level overview of country-level issues relating to grids, this is a macro view, and needs to be complemented by more detailed policy and technical analysis to properly assess grid readiness at the country level, again in consultation with national stakeholders. This also speaks to the importance of qualitative assessment. The data collected against the Key Indicators is illuminating, however it should be paired with qualitative assessment that examine policy settings, regulatory frameworks, operational requirements etc., that are non-quantifiable.

The current exercise examined eleven countries in the Asia-Pacific region. To truly glean robust cross-country regional themes of the kind discussed in Section 5 below, it would be useful to examine a larger sample size of countries, including a representative mix of countries in different geographies, with diverse levels of development and with various levels of progress in terms of power system transitions.

5. Regional Themes Emerging from the Assessment

A number of key themes emerged from the current analysis in terms of the current status of grid health and development across the Asia-Pacific. To begin with, effectively all countries surveyed faced issues and challenges in optimizing and effectively developing national grids. While at times these issues were diverse and context-specific (for example Japan's frequency mismatch across internal regions), at other times they were very consistent across countries, especially across countries with similar levels of development.

For example, developed countries (such as Australia, Japan, the Republic of Korea and Singapore) tended to encounter technical and procedural challenges to grid expansion, while developing countries (such as much of Southeast Asia) tended to face issues relating to finance and project development. Developed countries with higher levels of VRE penetration tended to face serious issues in the fundamental transformation and modernization of grid systems to make them fit for purpose for a high-VRE future. On the other hand, developing countries faced challenges in sufficiently developing grids for power system resilience and reliability. While technical analysis suggests that many developing countries could effectively integrate higher levels of VRE with current grid configurations, this implies that the current issues these countries face vis-à-vis grid development will be compounded after VRE penetration reaches a certain level, without action now.

Interestingly, a serious challenge to grid development in developed countries was project approval processes, which were often beset by onerous bureaucratic hurdles and general public opposition. Policymakers and national authorities have the opportunity to re-examine these processes to make them more streamlined and to potentially strengthen compensation regulations. Without this, plans and projects are likely to continue to languish.

While significantly more acute in developing countries, finance remains a largely universal issue across countries. While policymakers should examine innovative funding options and structured financing models, simple institutional changes, particularly in developing countries, could help to encourage financial flows – for example, allowing private sector investment in and development of grid infrastructure where this is limited, and a general move towards cost-reflective tariffs in subsidized systems. It is clear that the policy and regulatory frameworks governing the grids sector are currently not fit for purpose given the scale of the investment and financing challenge faced, including in developed countries. While the process of optimizing these frameworks will be highly country-specific, best practices are emerging. These should be highlighted in further analytical work. Without regulatory optimization, the financing challenge will likely remain acute.

6. Country Data for Key Indicators

Table 2: Grid Readiness Data by Country

Grid Assessment	Indicators	Australia	Cambodia	Indonesia	Japan	Kazakhstan	Lao PDR	Philippines	Republic of Korea	Singapore	Tajikistan	Thailand
		Countries										
Power Sector Transition	Share of RE in power generation (%)	35.12%	61.00%	20.00%	25.86%	12.31%	76.71%	22.13%	8.38%	5.17%	92.59%	23.00%
	Share of VRE in power generation (%)	28.57%	6.67%	0.22%	11.38%	4.09%	0.15%	2.56%	5.87%	2.05%	0.01%	4.48%
	Annual growth in VRE penetration (average % over 5 years)	4.75%	2.36%	0.16%	1.59%	1.52%	0.01%	0.39%	1.93%	1.14%	0.01%	4.36%
	MW of VRE in connection queue	50GW	5.9GW	N/A	N/A	N/A	N/A	N/A	17.9GW	N/A	N/A	N/A
	Annual growth in electricity demand (average % over 5 years)	1.92%	13.64%	8.07%	-1.92%	1.74%	21.09%	2.20%	0.63%	1.54%	1.31%	2.49%
	Demand projection vs generation supply target (2030) (TWh)	Demand: 270 TWh Generation: 328 TWh	Demand: 30.1 - 36.5 TWh Generation: 36.5 TWh	Demand: 445 TWh Generation: 487 TWh	Demand: 850 TWh Generation: 890 TWh	Demand: 135 TWh Generation 121.5 TWh	Demand: 9.7 TWh Generation: 104 TWh	N/A	Demand: 572.8 TWh Generation: 641.4 GW	Demand: 71.3 - 76.4 TWh	Demand: 31.1 TWh Generation: 45 TWh	Demand: 282.4 TWh Generation: 259.3 TWh
	Independent regulatory body	Yes	Yes	No	No	No	No	Yes	No	No	No	Yes
Grid Development	Transmission circuit length (km)	54807 km (2025)	6221 km (2023)	67752 km (2023)	180060 km (2023)	27905 km(2024)	9822 km (2020)	23109 km (2024)	35400 km (2023)	9360 km (2022)	N/A	40125 (2025)
	Annual growth in transmission expansion, kms (average % over 5 years)	3.15%	14.32%	7.25%	0.13%	0.75%	N/A	0.71%	1.42%	N/A	N/A	2.65%
	Transmission transformer capacity (MVA)	N/A	N/A	77514 MVA (2022)	868556 MVA (2022)	38893 (2024)	N/A	58653 MVA (2024)	N/A	N/A	N/A	147574 MVA (2025)
	Interconnections with neighbouring countries	No	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes
	Current interconnections capacity (MW)	0	Grid-to-grid: Cambodia - Viet Nam 200 MW Cambodia - Lao PDR 300 MW Cambodia - Thailand 250 MW Generation-tied: Cambodia - Thailand 195 MW	Grid-to-grid: West Kalimantan - Sarawak 230 MW	0	N/A	Grid-to-grid: Lao PDR - Thailand 955 MW Lao PDR - Cambodia 300 MW Lao PDR - Myanmar 30 MW	0	0	Grid-to-grid: Singapore - Malaysia 525 MW	N/A	Grid-to-grid: Thailand - Lao PDR 955 MW Thailand - Cambodia 250 MW Thailand - Malaysia 380 MW
	Private participation/investment in transmission	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	No
Grid Operation	RE curtailment rate (%)	3.80%	N/A	N/A	1.87%	N/A	N/A	N/A	Jeju: 5.09%	N/A	N/A	N/A
	Grid losses (%)	4.7%	10.6%	8.7%	4.9%	15.0%	28.2%	10.8%	3.2%	1.1%	22.3%	6.8%
	System Flexibility (WEF 2024 indicator, 0-100)	26.37	53.39	38.21	50.58	28.88	72.88	39.34	32.80	98.28	94.22	76.00
	RE Priority dispatch	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes
	Economic grid tariff determination	No	No	No	No	No	No	No	No	No	No	No
Consumer/ demand-side	SAIFI & SAIDI	SAIFI:1.00 SAIDI:0.60	SAIFI:15.35 SAIDI:20.78	SAIFI:2.18 SAIDI:2.82	SAIFI:0.02 SAIDI:0.02	SAIFI:0.91 SAIDI:0.96	SAIFI:22.70 SAIDI:3.96	SAIFI:2.23 SAIDI:3.57	SAIFI:0.05 SAIDI:0.04	SAIFI:0.11 SAIDI:0.06	SAIFI:3.00 SAIDI:2.17	SAIFI:0.72 SAIDI:0.38
	Cost-reflective tariffs	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No
	Electricity access (% of population, 2022)	100%	88.4%	99.6%	100%	100%	95.3%	96.2%	100%	100%	100%	100%
	Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
	Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distribution	Distribution loss (%)	4.10%	13.65%	7.18%	4.42%	8.27%	4.68%	9.59%	3.31%	0.30%	18.24%	7.36%
	Distribution circuit length (km)	7677987 km (2023)	N/A	946101 km (2022)	4133114 km (2023)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Annual growth in distribution expansion (average & over 5 years)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Distribution transformer capacity (MVA)	N/A	N/A	41987 MVA (2022)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

7. An Assessment of Grid Readiness by Country in Brief

The following section provides brief analysis on grid readiness for the eleven Asia-Pacific countries that have been examined, based on Key Indicators and other data collected as part of this exercise. Countries were selected to ensure broad representation across levels of development, grid attributes and energy resource endowments.

Australia

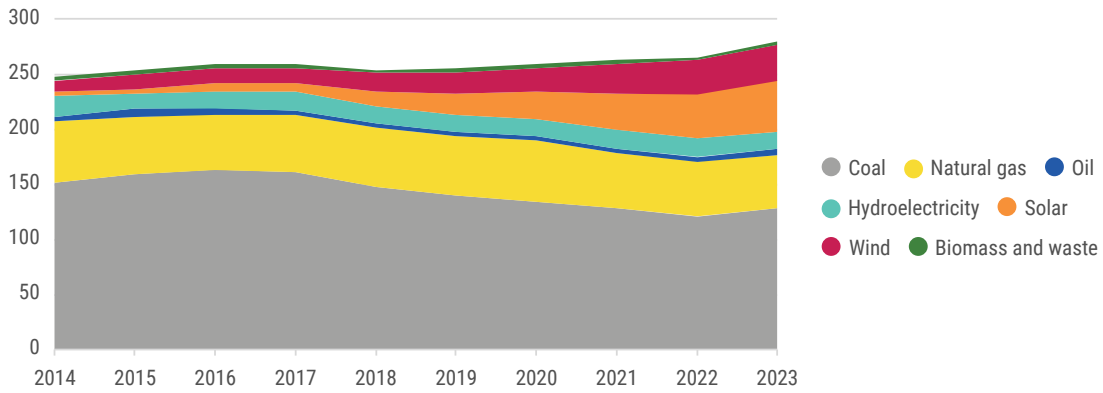
In 2022, the Australian Energy Market Operator (AEMO) released an Integrated System Plan with an 'Optimal Development Path' that sets out a transmission expansion plan to connect renewable energy generation with major load centres, facilitating VRE integration and outlining significant investment in transmission infrastructure to enhance grid capacity, with a headline investment target of approximately USD20 billion by 2050.

Australia is undertaking a process of power decarbonization at a scale and pace almost unmatched globally, led by huge increases in wind and solar penetration and aided by new large-scale hydro facilities plus a boom in storage project investment.

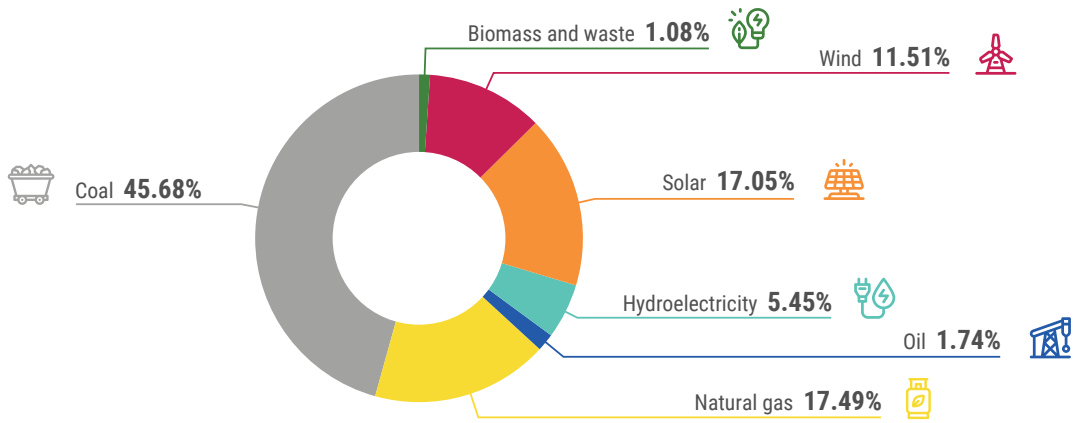
This has placed considerable pressure on a transmission system – already one of the longest in the world – designed for decades to transport power from large mine-mouth coal plants to urban centres.

Various power sector agencies and successive governments recognize these challenges and have, respectively, put in place enabling policies and public finance to encourage investment. Key to achievement of goals will be to streamline and simplify various approval processes to ensure infrastructure is built in a timely fashion.

Australia Power Generation by Source (billion kWh, 2014-2023)



Australia Power Generation Mix (2023)



Grid Readiness Data - Australia

Power Sector Transition

Share of RE in power generation (%)	35.12%
Share of VRE in power generation (%)	28.57%
Annual growth in VRE penetration (average % over 5 years)	4.75%
MW of VRE in connection queue	50GW
Annual growth in electricity demand (average % over 5 years)	1.92%
Demand projection vs generation supply target (2030) (TWh)	Demand: 270 TWh Generation: 328 TWh
Independent regulatory body	Yes

Grid Development

Transmission circuit length (km)	54807 km (2025)
Annual growth in transmission expansion, kms (average % over 5 years)	3.15%
Transmission transformer capacity (MVA)	N/A
Interconnections with neighbouring countries	No
Current interconnections capacity (MW)	0
Private participation/ investment in transmission	Yes

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:1.00 SAIDI:0.60
Cost-reflective tariffs	Yes
Electricity access (% of population, 2022)	100%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	4.10%
Distribution circuit length (km)	7677987 km (2023)
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	3.80%
Grid losses (%)	4.7%
System Flexibility (WEF 2024 indicator, 0-100)	26.37
RE Priority dispatch	Yes
Economic grid tariff determination	No

Cambodia

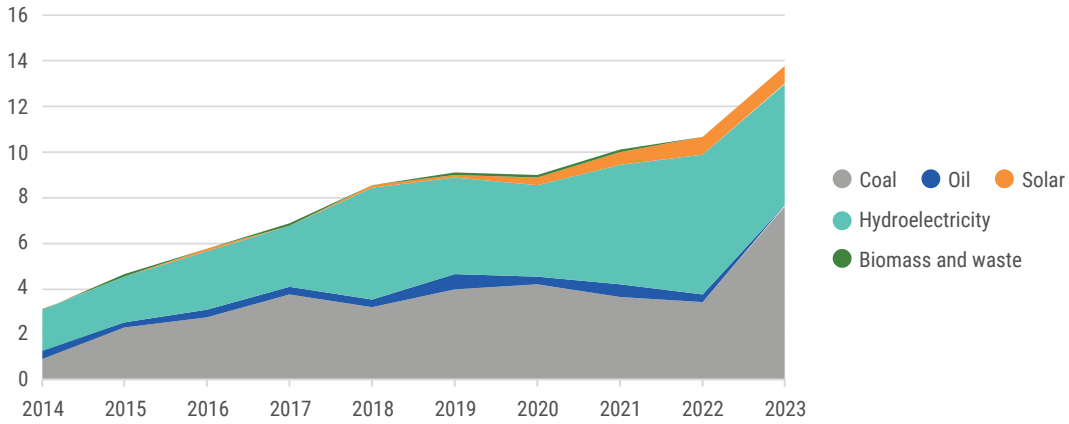
The Power Development Master Plan (2022-2040) aims for the construction of new 230 kilovolt (kV) and 500 kV transmission lines, installation of transformers, reactive plants, series capacitors, and resilience upgrades to enhance grid reliability and capacity, while expanding power imports from neighbouring countries. The power development plan (PDP) estimates total investment needs of approximately USD1.796 billion for network expansion from 2022 to 2040. This includes USD816 million allocated for priority projects by 2025 and an additional USD980 million for further infrastructure developments up to 2040.

In line with its 2050 net zero target, the 2023 PDP (scheduled for revision in June 2025) reflects more ambitious targets for VRE deployment and cross-border interconnection with neighboring countries. The PDP also calls for significant expansion of 230 kV and 500 kV transmission infrastructure.

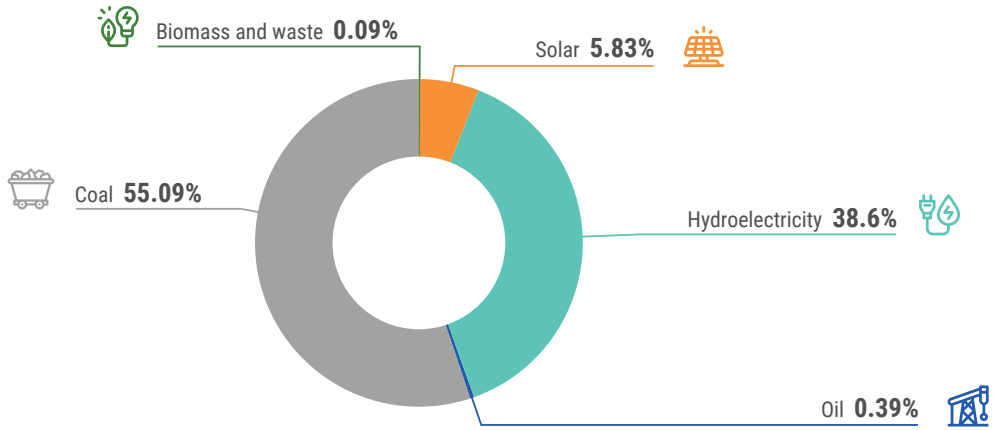
Coal-fired power plants still play a significant role in Cambodia's power generation mix, with fuel inputs largely dependent on imports. Both generation and grid infrastructure face limitations in flexibility and reliability, posing challenges for integrating VRE and expanding regional interconnection. Perhaps most importantly, the PDP estimates that grid upgrades are likely cost approximately USD1.8 billion. Raising this finance is likely to be a significant challenge.

As the share of VRE grows and efforts towards regional power interconnection accelerate, it will be critical to find innovative sources of finance to strengthen both grid infrastructure and system reliability, including perhaps through institutional reforms in the power sector, and public finance to encourage investment.

Cambodia Power Generation by Source (billion kWh, 2014-2023)



Cambodia Power Generation Mix (2023)



Grid Readiness Data - Cambodia

Power Sector Transition

Share of RE in power generation (%)	61.00%
Share of VRE in power generation (%)	6.67%
Annual growth in VRE penetration (average % over 5 years)	2.36%
MW of VRE in connection queue	5.9GW
Annual growth in electricity demand (average % over 5 years)	13.64%
Demand projection vs generation supply target (2030) (TWh)	Demand: 30.1 - 36.5 TWh Generation: 36.5 TWh
Independent regulatory body	Yes

Grid Development

Transmission circuit length (km)	6221 km (2023)
Annual growth in transmission expansion, kms (average % over 5 years)	14.32%
Transmission transformer capacity (MVA)	N/A
Interconnections with neighbouring countries	Yes
Current interconnections capacity (MW)	Grid-to-grid: Cambodia - Viet Nam: 200 MW Cambodia - Lao PDR 300 MW Cambodia - Thailand 250 MW Generation-tied: Cambodia - Thailand 195 MW
Private participation/ investment in transmission	Yes

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:15.35 SAIDI:20.78
Cost-reflective tariffs	No
Electricity access (% of population, 2022)	88.4%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	4.10%
Distribution circuit length (km)	7677987 km (2023)
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	N/A
Grid losses (%)	10.6%
System Flexibility (WEF 2024 indicator, 0-100)	53.39
RE Priority dispatch	No
Economic grid tariff determination	No

Indonesia

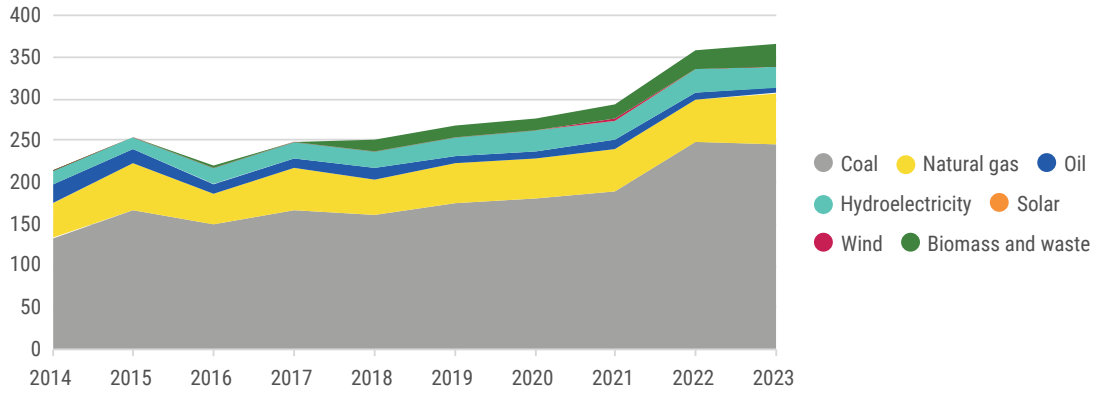
The current National Power Supply Plan (RUPTL) envisages a total expansion of 32,237 km in line length and 55.8 gigavolt amperes (GVA) of transformer capacity to be added by 2030, in addition to cross-border interconnection development (Peninsular Malaysia-Sumatra, Batam-Singapore, Sabah-East Kalimantan), with a total cost of approximately USD10 billion.

The transmission network in Indonesia has expanded significantly in recent years, with future ambitions to connect major islands and develop inter-island grids. The State Electricity Company (PLN) has outlined a clear strategy to integrate more renewables through RUPTL 2021–2030. Along with the development of renewables, technical and regulatory frameworks are gradually being aligned with energy transition imperatives, including environmental reviews and renewable targets.

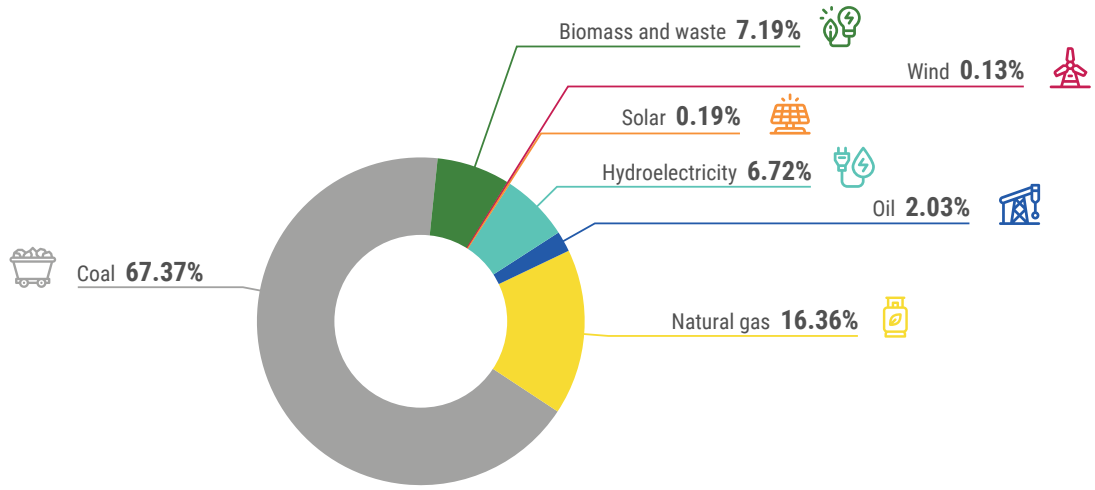
From a low base, in some areas VRE development is progressing faster than transmission infrastructure, leading to risks of curtailment and instability in local grids, especially given currently high rate of transmission losses. The financial sustainability of PLN remains a consistent issue for large-scale grid expansion, including the ambition for inter-island interconnection.

Indonesia's complex geography and regional diversity present unique challenges to grid modernization. While political and institutional frameworks are supportive of clean energy, enhanced investment, decentralized planning, and technology upgrades (particularly grid flexibility and dispatch) are essential to accelerate the energy transition in Indonesia. Policymakers should carefully explore ways to channel private finance into the transmission sector, which is currently blocked by existing regulations.

Indonesia Power Generation by Source (billion kWh, 2014-2023)



Indonesia Power Generation Mix (2023)



Grid Readiness Data - Indonesia

Power Sector Transition

Share of RE in power generation (%)	20.00%
Share of VRE in power generation (%)	0.22%
Annual growth in VRE penetration (average % over 5 years)	0.16%
MW of VRE in connection queue	N/A
Annual growth in electricity demand (average % over 5 years)	8.07%
Demand projection vs generation supply target (2030) (TWh)	Demand: 445 TWh Generation: 487 TWh
Independent regulatory body	No

Grid Development

Transmission circuit length (km)	67752 km (2023)
Annual growth in transmission expansion, kms (average % over 5 years)	7.25%
Transmission transformer capacity (MVA)	77514 MVA (2022)
Interconnections with neighbouring countries	Yes
Current interconnections capacity (MW)	Grid-to-grid: West Kalimantan - Sarawak 230 MW
Private participation/ investment in transmission	Yes

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:2.18 SAIDI:2.82
Cost-reflective tariffs	No
Electricity access (% of population, 2022)	99.6%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	7.18%
Distribution circuit length (km)	946101 km (2022)
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	41987 MVA (2022)

Grid Operation

RE curtailment rate (%)	N/A
Grid losses (%)	8.7%
System Flexibility (WEF 2024 indicator, 0-100)	38.21
RE Priority dispatch	Yes
Economic grid tariff determination	No

Japan

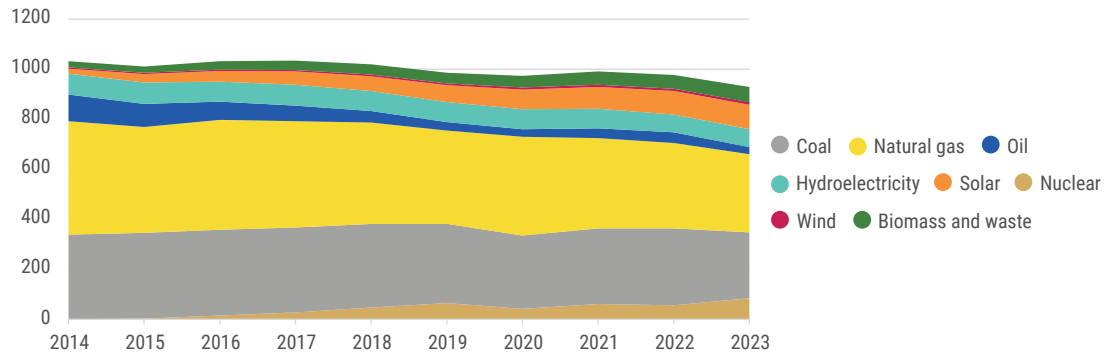
The 2050 Master Plan aims to connect Tokyo with the northern regions of Tohoku and Hokkaido, rich in solar and wind energy potential. Between 2030 and 2050, it sets out a 25 per cent increase in transmission capacity, with a cost of USD50 billion to support the integration of VRE and enhance grid resilience.

Japan is aiming to achieve 50-60 per cent renewables in the energy mix by 2050 by developing offshore wind, solar, and hydrogen. The power grids in eastern (50 hertz (Hz)) and western regions (60 Hz) operate at different frequencies, making it challenging to transfer electricity between the two regions, resulting in the two systems being managed separately. To address this issue the government is investing in reinforcing its power grids, including through the development of transmission infrastructure, which allows for a bypassing of the frequency barrier and enables electricity to be transferred efficiently between regions.

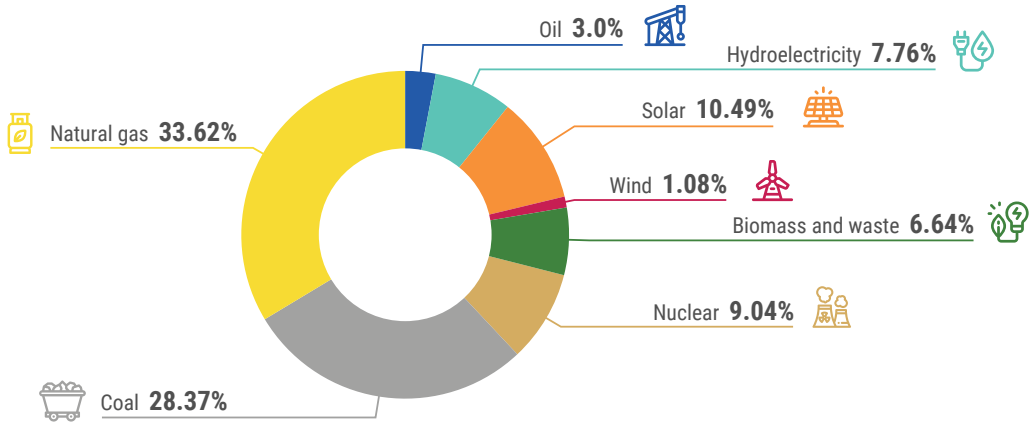
Japan possesses significant potential for offshore wind and solar generation. However, the frequency divide and energy strategy favouring nuclear power to achieve carbon neutrality by 2050 have constrained renewables penetration. Despite high levels of solar energy production in regions such as Kyushu, nuclear power being operated at baseload and the limited capacity to export surplus renewable energy to other demand centers in Japan has led to significant curtailment in recent years.

Japan's grid modernization efforts focusing on improving interconnectivity between regions and increasing renewables integration are driving expansion in infrastructure, adoption of smart inverters and grid-scale battery initiatives. If realized, these investments and innovations will be critical to advancing grid management, transmission system development and VRE integration in the coming years.

Japan Power Generation by Source (billion kWh, 2014-2023)



Japan Power Generation Mix (2023)



Grid Readiness Data - Japan

Power Sector Transition

Share of RE in power generation (%)	25.86%
Share of VRE in power generation (%)	11.38%
Annual growth in VRE penetration (average % over 5 years)	1.59%
MW of VRE in connection queue	N/A
Annual growth in electricity demand (average % over 5 years)	-1.92%
Demand projection vs generation supply target (2030) (TWh)	Demand: 850 TWh Generation: 890 TWh
Independent regulatory body	No

Grid Development

Transmission circuit length (km)	180060 km (2023)
Annual growth in transmission expansion, kms (average % over 5 years)	0.13%
Transmission transformer capacity (MVA)	868556 MVA (2022)
Interconnections with neighbouring countries	No
Current interconnections capacity (MW)	0
Private participation/ investment in transmission	Yes

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:0.02 SAIDI:0.02
Cost-reflective tariffs	Yes
Electricity access (% of population, 2022)	100%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	4.42%
Distribution circuit length (km)	4133114 km (2023)
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	1.87%
Grid losses (%)	4.9%
System Flexibility (WEF 2024 indicator, 0-100)	50.58
RE Priority dispatch	No
Economic grid tariff determination	No

Kazakhstan

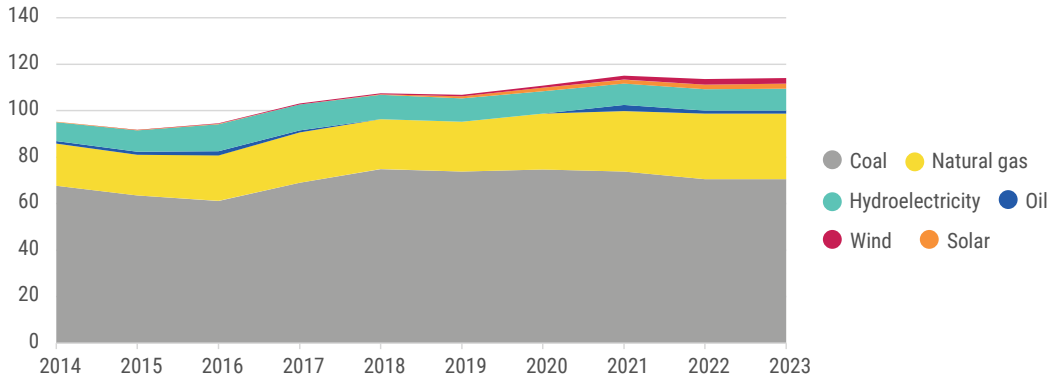
The National Energy Strategy aims to integrate the West Kazakhstan Power System into the Unified Power System of Kazakhstan, with investment in transmission projects to bolster its export and transit potential, facilitating electricity transmission from the Russian Federation to Central Asian countries. Investment for 15 priority projects is valued at USD3 billion by 2025 and USD63 billion until 2040, including USD9 billion in power distribution networks, and USD17 billion in regional transmission projects.

Deployment of renewable energy, including wind and solar, is gradually increasing, supported by government incentives and actions. At the same time, there is a strong focus on expanding transmission capacity, modernizing its grid infrastructure, and improving overall system reliability and flexibility.

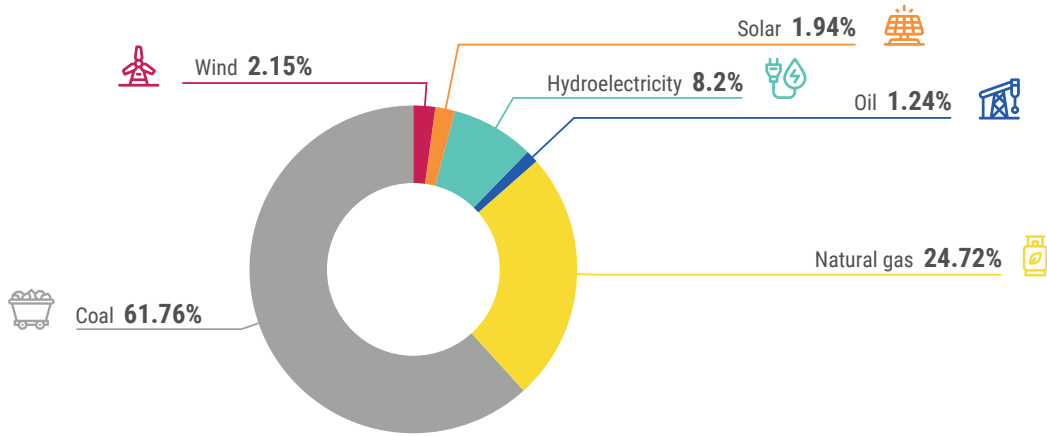
Key challenges include ageing infrastructure, most of which date to the Soviet period, high transmission losses as a result, and a perceived tension between renewable energy integration and grid stability.

Kazakhstan has huge renewable potential, but achieving long-term sustainability and energy security will require continued infrastructure investment, regulatory improvements, and additional market reforms to unlock this potential.

Kazakhstan Power Generation by Source (billion kWh, 2014-2023)



Kazakhstan Power Generation Mix (2023)



Grid Readiness Data - Kazakhstan

Power Sector Transition

Share of RE in power generation (%)	12.31%
Share of VRE in power generation (%)	4.09%
Annual growth in VRE penetration (average % over 5 years)	1.52%
MW of VRE in connection queue	N/A
Annual growth in electricity demand (average % over 5 years)	1.74%
Demand projection vs generation supply target (2030) (TWh)	Demand: 135 TWh Generation 121.5 TWh
Independent regulatory body	No

Grid Development

Transmission circuit length (km)	27905 km (2024)
Annual growth in transmission expansion, kms (average % over 5 years)	0.75%
Transmission transformer capacity (MVA)	38893 MVA (2024)
Interconnections with neighbouring countries	Yes
Current interconnections capacity (MW)	N/A
Private participation/ investment in transmission	Yes

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:0.91 SAIDI:0.96
Cost-reflective tariffs	No
Electricity access (% of population, 2022)	100%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	8.27%
Distribution circuit length (km)	N/A
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	N/A
Grid losses (%)	15.0%
System Flexibility (WEF 2024 indicator, 0-100)	28.88
RE Priority dispatch	Yes
Economic grid tariff determination	No

Lao People's Democratic Republic (Lao PDR)

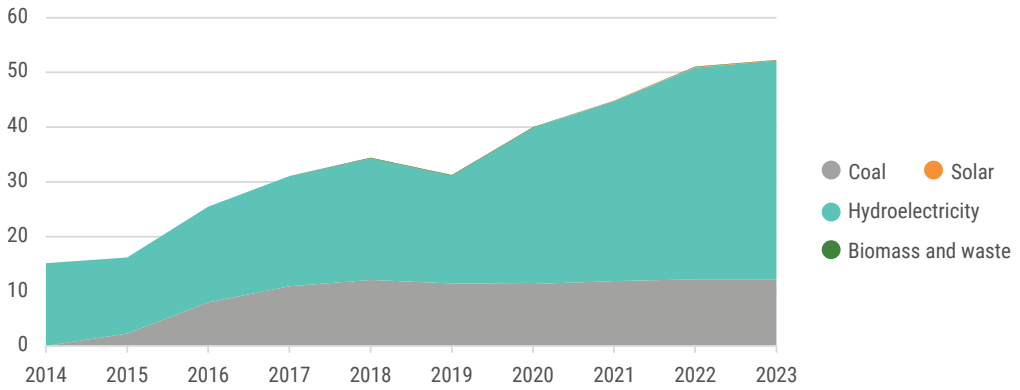
The National Power Development Plan 2020-2030 envisages grid expansion that creates a backbone to integrate currently unconnected regions domestically while prioritizing development of cross-border infrastructure to facilitate power trade, supporting the goal of becoming a major exporter of clean energy.

Lao PDR has committed to a 2050 net zero target, building on its already hydro-dominated power system serving for both domestic consumption and export. The country is actively advancing grid-to-grid bilateral and multilateral pilot projects with neighboring nations and enhancing its comprehensive power system planning efforts aligned with its ambition to become the "Battery of Southeast Asia."

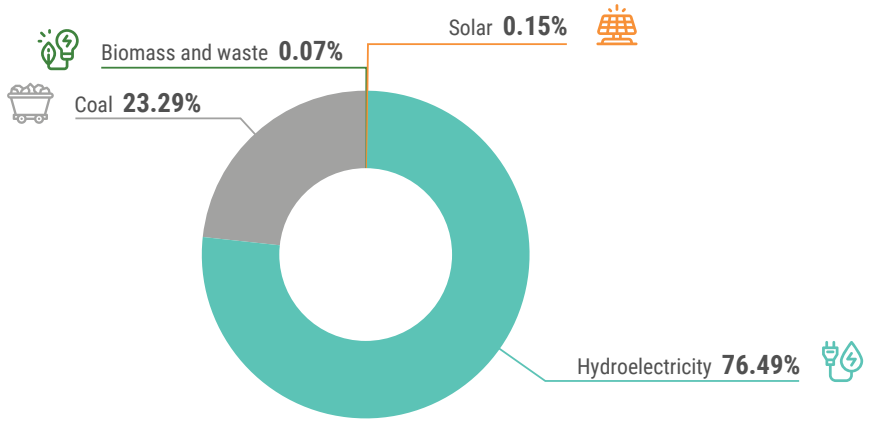
The seasonal nature of hydropower places pressure on Lao PDR to meet electricity demand during dry periods, especially as demand continues to rise. While the country is actively exploring VRE options through international partnerships, grid integration is constrained by a weak transmission network, frequent large-scale outages, and limited financing capacity.

With abundant hydropower resources and a strategic geographic position, Lao PDR can play a central role in advancing regional power interconnection, through both IPP-to-grid and grid-to-grid interconnection models. However, to fully realize its green energy potential and integrate more VRE into the domestic grid, urgent efforts are needed to mobilize financing for transmission, distribution, and large-scale energy storage infrastructure.

Lao PDR Power Generation by Source (billion kWh, 2014-2023)



Lao PDR Power Generation Mix (2023)



Grid Readiness Data - Lao PDR

Power Sector Transition

Share of RE in power generation (%)	76.71%
Share of VRE in power generation (%)	0.15%
Annual growth in VRE penetration (average % over 5 years)	0.01%
MW of VRE in connection queue	N/A
Annual growth in electricity demand (average % over 5 years)	21.09%
Demand projection vs generation supply target (2030) (TWh)	Demand: 9.7 TWh Generation: 104 TWh
Independent regulatory body	No

Grid Development

Transmission circuit length (km)	9822 km (2020)
Annual growth in transmission expansion, kms (average % over 5 years)	N/A
Transmission transformer capacity (MVA)	N/A
Interconnections with neighbouring countries	Yes
Current interconnections capacity (MW)	Grid-to-grid: Lao PDR - Thailand 955 MW Lao PDR - Cambodia 300 MW Lao PDR - Myanmar 30 MW
Private participation/ investment in transmission	No

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:22.70 SAIDI:3.96
Cost-reflective tariffs	No
Electricity access (% of population, 2022)	95.3%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	4.68%
Distribution circuit length (km)	N/A
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	N/A
Grid losses (%)	28.2%
System Flexibility (WEF 2024 indicator, 0-100)	72.88
RE Priority dispatch	No
Economic grid tariff determination	No

Philippines

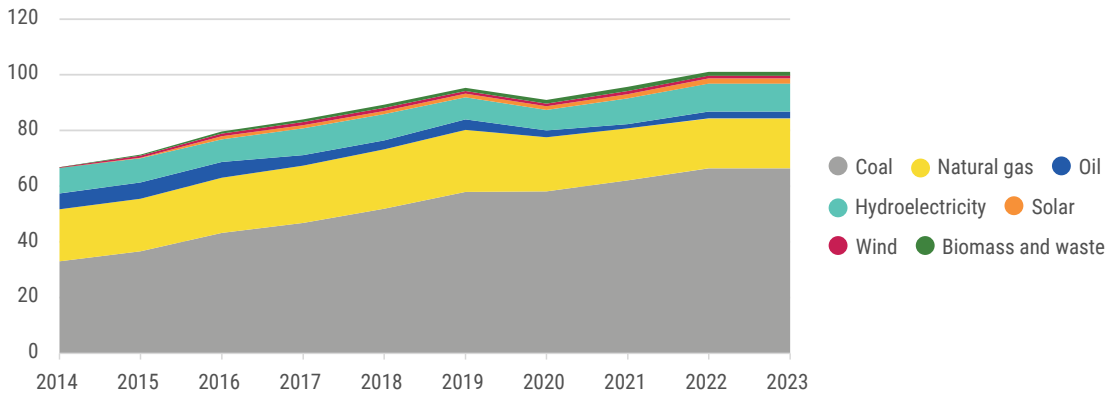
The Transmission Development Plan 2025-2050 aims to expand and modernize the transmission network, adding 3,871 km of lines and 34,150 MVA of capacity by 2040, including over 100 transmission projects, with a cost of USD16 billion for high-voltage grids between 2024 and 2034.

The Philippines Energy Regulatory Commission's authority has been strengthened to facilitate the timely completion of critical transmission projects, to meet current demand and to prepare for enhanced renewables integration in the coming years. Smart grid initiatives and policies supporting VRE integration are in place, including priority dispatch and a renewable portfolio standards.

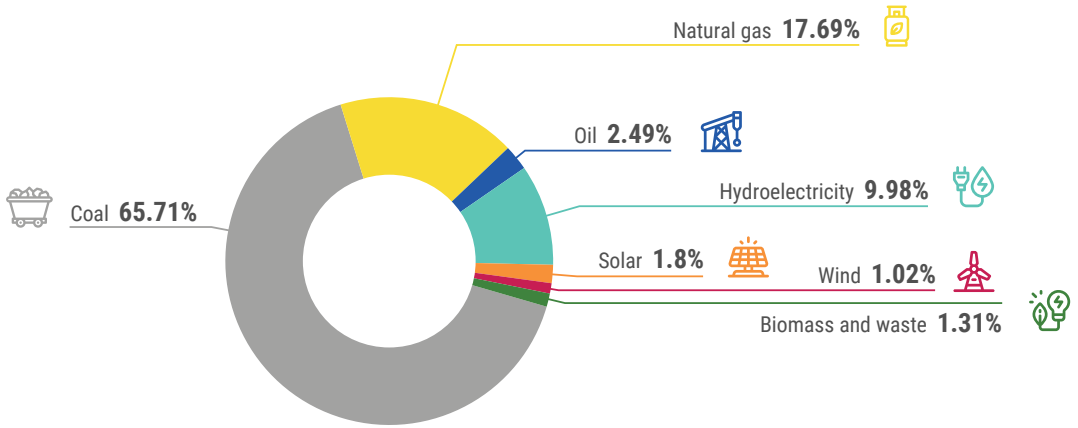
As with Indonesia, the country's archipelagic geography complicates grid development programs and presents practical challenges to transmission infrastructure expansion, particularly for inter-island connectivity. Grid reliability issues remain, especially in remote areas, with SAIFI and SAIDI values significantly higher than ASEAN averages, which is likely to impede future VRE integration. Apart from physical constraints, recurring project delays due to patchy project implementation have further hampered transmission expansion.

Efforts to expand VRE deployment thus far have had limited success. Despite strong policy commitments and increasing private sector participation in renewable energy development, the actual integration of renewables remains constrained by the coal-dominated generation mix. Achieving a sustainable energy transition will require substantial investment in new grid infrastructure, enhanced regulatory enforcement, and accelerated grid modernization.

Philippines Power Generation by Source (billion kWh, 2014-2023)



Philippines Power Generation Mix (2023)



Grid Readiness Data - Philippines

Power Sector Transition

Share of RE in power generation (%)	22.13%
Share of VRE in power generation (%)	2.56%
Annual growth in VRE penetration (average % over 5 years)	0.39%
MW of VRE in connection queue	N/A
Annual growth in electricity demand (average % over 5 years)	2.20%
Demand projection vs generation supply target (2030) (TWh)	N/A
Independent regulatory body	Yes

Grid Development

Transmission circuit length (km)	23109 km (2024)
Annual growth in transmission expansion, kms (average % over 5 years)	0.71%
Transmission transformer capacity (MVA)	58653 MVA (2024)
Interconnections with neighbouring countries	No
Current interconnections capacity (MW)	0
Private participation/ investment in transmission	Yes

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:2.23 SAIDI:3.57
Cost-reflective tariffs	Yes
Electricity access (% of population, 2022)	96.2%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	9.59%
Distribution circuit length (km)	N/A
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	N/A
Grid losses (%)	10.8%
System Flexibility (WEF 2024 indicator, 0-100)	39.34
RE Priority dispatch	Yes
Economic grid tariff determination	No

Republic of Korea

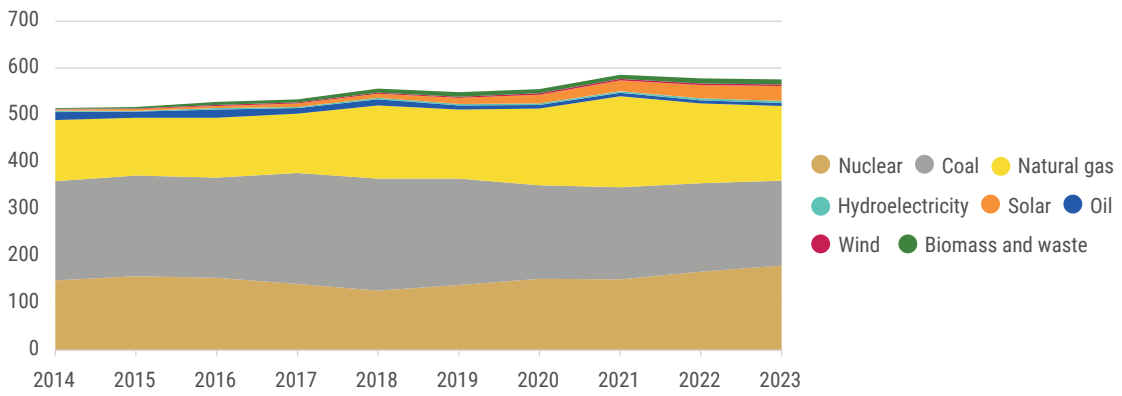
The 2023 Basic Plan for Long-term Electricity Supply and Demand sets out a 15-year plan for investing approximately USD40 billion in the expansion of transmission, distribution lines and substations to accommodate the anticipated changes in power generation and consumption as a result of a quadrupling of VRE capacity by 2038. This represents close to double the amount that was included in the 2021 Basic Plan.

Republic of Korea is committed to Net Zero 2050 and updates its Basic Plan for Long-term Electricity Supply every two years with a 15-year outlook, covering renewable energy targets and grid expansion. The power grid is known for its high efficiency, flexibility, and digitalization. The country is also advancing smart grid development and updating grid codes to support VRE integration.

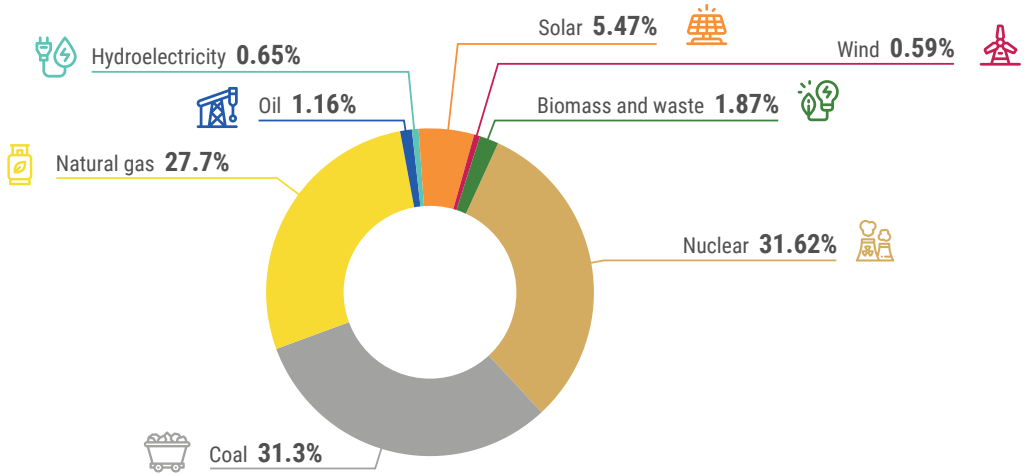
The country's energy mix remains heavily reliant on imported fossil fuels, with renewables still playing a minor role in the current generation mix. Financing limitations, coupled with public opposition to new transmission infrastructure, further complicate efforts to expand grids and enable VRE deployment.

Republic of Korea has built a strong technical foundation for a modern and efficient power grid, supported by progress in smart grid development and regulatory updates. It is essential to address challenges such as fossil fuel dependency, utility financial health, and public resistance to grid expansion. While expediting domestic transmission network construction, the country can mobilize financing and technical innovation, and explore power connectivity opportunities to enhance energy security and regional cooperation.

Republic of Korea Power Generation by Source (billion kWh, 2014-2023)



Republic of Korea Power Generation Mix (2023)



Grid Readiness Data - Republic of Korea

Power Sector Transition

Share of RE in power generation (%)	8.38%
Share of VRE in power generation (%)	5.87%
Annual growth in VRE penetration (average % over 5 years)	1.93%
MW of VRE in connection queue	17.9GW
Annual growth in electricity demand (average % over 5 years)	0.63%
Demand projection vs generation supply target (2030) (TWh)	Demand: 572.8 TWh Generation: 641.4 GW
Independent regulatory body	No

Grid Development

Transmission circuit length (km)	35400 km (2023)
Annual growth in transmission expansion, kms (average % over 5 years)	1.42%
Transmission transformer capacity (MVA)	N/A
Interconnections with neighbouring countries	No
Current interconnections capacity (MW)	0
Private participation/ investment in transmission	No

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:0.05 SAIDI:0.04
Cost-reflective tariffs	Yes
Electricity access (% of population, 2022)	100%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	3.31%
Distribution circuit length (km)	N/A
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	Jeju: 5.09%
Grid losses (%)	3.2%
System Flexibility (WEF 2024 indicator, 0-100)	32.80
RE Priority dispatch	Yes
Economic grid tariff determination	No

Singapore

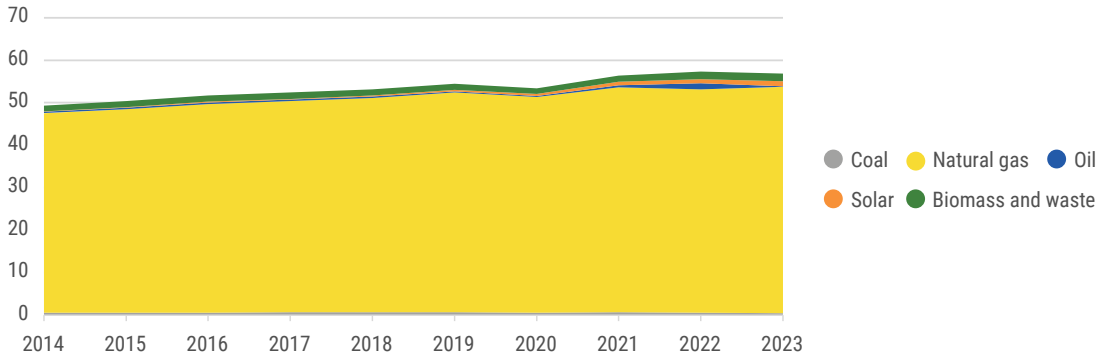
Singapore's Energy Market Authority (EMA) has set out a 10-year Transmission Development Plan that ensures transmission networks meet the security, reliability, stability, and adequacy standards of the power system, with key innovations including Singapore's first 230kV underground electricity substation. EMA has delivered interim approvals for the import of 7.35 GW of clean energy from Southeast Asia and Australia, chiefly via subsea cable.

The digitalization of Singapore's grid network has reached an advanced level and is expected to be further enhanced under the recent Energy Grid 2.0 roadmap. Grid infrastructure and planning are tightly regulated by EMA, supporting efforts to add domestic solar capacity and promoting imports of clean power from around Southeast Asia and beyond.

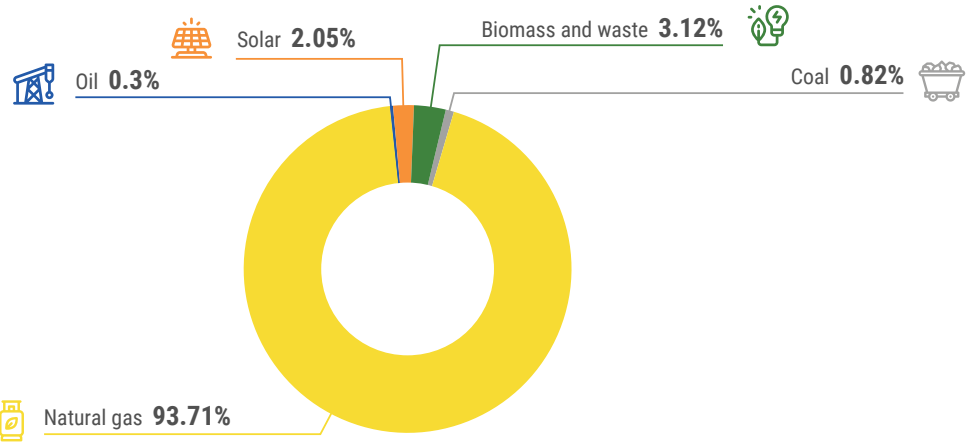
VRE deployment, grid upgrades and transmission expansion are all limited by space and land constraints. It will be absolutely critical for Singapore's power system decarbonization that plans for clean power import come to fruition, including complex and costly subsea projects with Southeast Asian neighbours.

Singapore operates one of the most advanced and reliable grids in the world with outstanding record of performance. Despite being exceptionally well-positioned for a smart, resilient energy future from a domestic perspective, power system transition will ultimately require significant expansion of clean power imports from ASEAN, requiring bilateral interconnection projects, sub-regional initiatives and progress at the regional level under the ASEAN Power Grid.

Singapore Power Generation by Source (billion kWh, 2014-2023)



Singapore Power Generation Mix (2023)



Grid Readiness Data - Singapore

Power Sector Transition

Share of RE in power generation (%)	5.17%
Share of VRE in power generation (%)	2.05%
Annual growth in VRE penetration (average % over 5 years)	1.14%
MW of VRE in connection queue	N/A
Annual growth in electricity demand (average % over 5 years)	1.54%
Demand projection vs generation supply target (2030) (TWh)	Demand: 71.3 - 76.4 TWh
Independent regulatory body	No

Grid Development

Transmission circuit length (km)	9360 km (2022)
Annual growth in transmission expansion, kms (average % over 5 years)	N/A
Transmission transformer capacity (MVA)	N/A
Interconnections with neighbouring countries	Yes
Current interconnections capacity (MW)	Grid-to-grid: Singapore - Malaysia 525 MW
Private participation/ investment in transmission	No

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:0.11 SAIDI:0.06
Cost-reflective tariffs	Yes
Electricity access (% of population, 2022)	100%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	No
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	0.30%
Distribution circuit length (km)	N/A
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	N/A
Grid losses (%)	1.1%
System Flexibility (WEF 2024 indicator, 0-100)	98.28
RE Priority dispatch	Yes
Economic grid tariff determination	No

Tajikistan

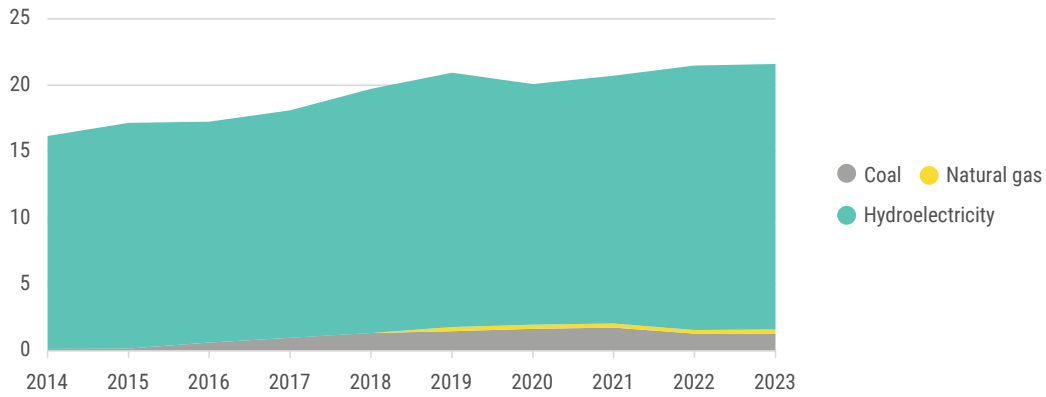
The National Development Strategy 2030 for the power sector aims for a 10 per cent reduction in transmission losses by 2030 through modernization and optimization of the network, the construction of 1,387 kilometers of high-voltage transmission lines and the establishment of converter stations in Sangtuda to facilitate the transmission of electricity to Afghanistan and Pakistan.

Tajikistan is working on regulatory reforms that would encourage private investment in grids, while also pursuing the development of connectivity projects like CASA-1000, which aims to export surplus summer electricity to South Asia.

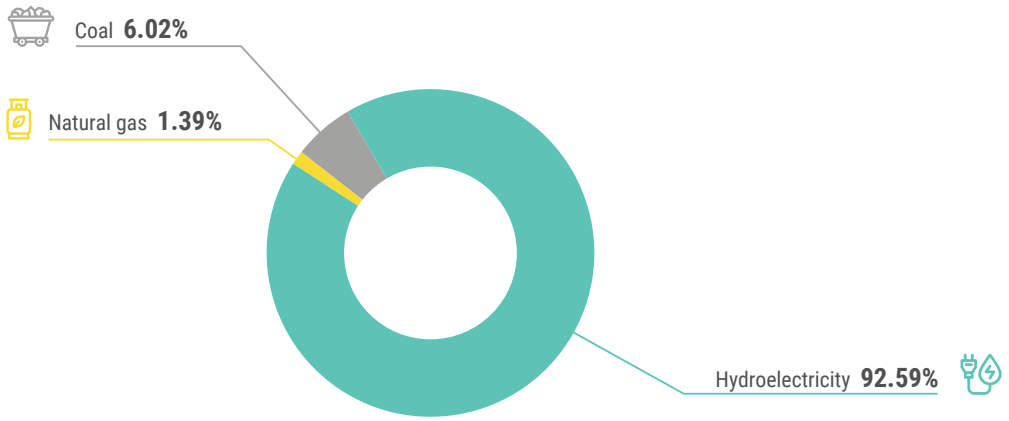
Key challenges include ageing infrastructure, high grid losses, seasonal supply constraints and limited energy storage capacity. Energy security remains a difficult challenge, particularly in winter when reduced hydropower output leads to shortages, suggesting some diversification of the generation mix is necessary.

Tajikistan has considerable renewable resources, and already operates a highly decarbonized power sector, with high shares of hydropower. Diversification and enhanced VRE deployment however will likely require continued infrastructure investment, regulatory improvements and market reform.

Tajikistan Power Generation by Source (billion kWh, 2014-2023)



Tajikistan Power Generation Mix (2023)



Grid Readiness Data - Tajikistan

Power Sector Transition

Share of RE in power generation (%)	92.59%
Share of VRE in power generation (%)	0.01%
Annual growth in VRE penetration (average % over 5 years)	0.01%
MW of VRE in connection queue	N/A
Annual growth in electricity demand (average % over 5 years)	1.31%
Demand projection vs generation supply target (2030) (TWh)	Demand: 31.1 TWh Generation: 45 TWh
Independent regulatory body	No

Grid Development

Transmission circuit length (km)	N/A
Annual growth in transmission expansion, kms (average % over 5 years)	N/A
Transmission transformer capacity (MVA)	N/A
Interconnections with neighbouring countries	Yes
Current interconnections capacity (MW)	N/A
Private participation/ investment in transmission	No

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:3.00 SAIDI:2.17
Cost-reflective tariffs	Yes
Electricity access (% of population, 2022)	100%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	No
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	18.24%
Distribution circuit length (km)	N/A
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	N/A
Grid losses (%)	22.3%
System Flexibility (WEF 2024 indicator, 0-100)	94.22
RE Priority dispatch	No
Economic grid tariff determination	No

Thailand

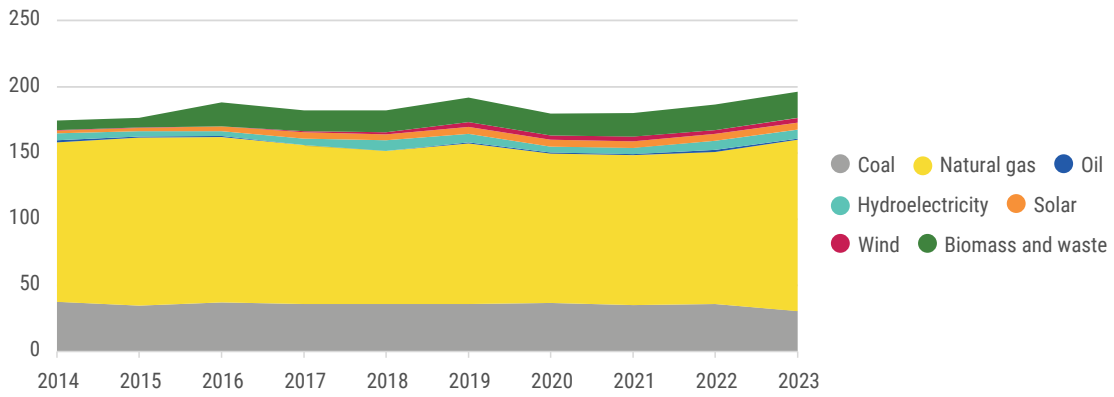
The current Power Development Plan aims to upgrade power lines from 115 kV to 500 kV or 800 kV to support the integration of VRE, the construction of 365 circuit-kilometres of transmission lines, establishing three new substations, expanding three existing substations, and installing transformers totaling 4,000 MVA, in Eastern Thailand. In addition, the Electricity Generating Authority of Thailand (EGAT) is planning for the upgrade of the Thailand–Malaysia interconnector, a 110-kilometer, 300 MW capacity line linking Khlong Ngae in Thailand to Gurun in Malaysia.

Thailand has a relatively strong internal transmission grid compared to ASEAN peers, as well as interconnections with four neighboring countries. While VRE penetration is currently low, the government and EGAT have set out plans to expand and strengthen grids with the stated aim of accommodating greater shares of VRE over time.

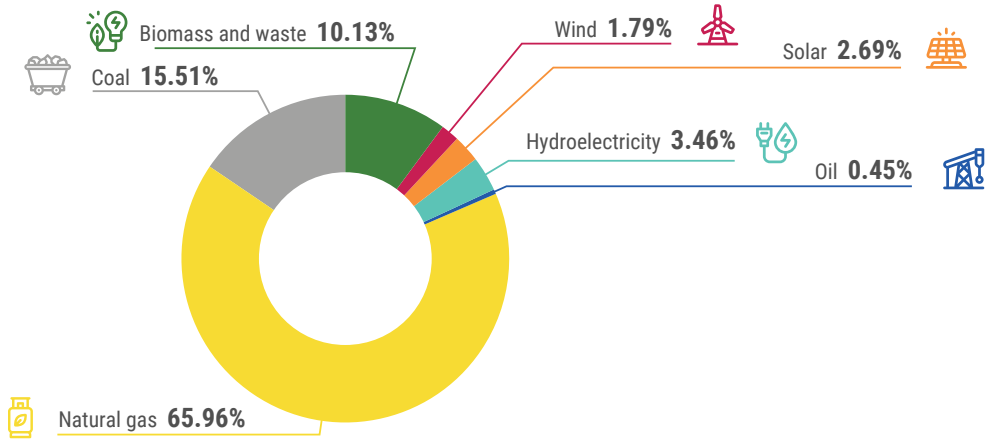
Practical implementation of grid strengthening programs is likely to be challenging. National stakeholders have limited experience in infrastructure-based VRE integration and integrated planning for clean energy deployment and transmission development is nascent. Finance is also likely to be a complicating factor, with EGAT currently the only entity authorized to make transmission system investments.

From a low base, Thailand's deployment of VRE has increased approximately ten-fold in the last decade, with clear ambitions existing to continue this process of power system transformation. As this takes place, greater stress will be placed on existing transmission infrastructure, requiring a more sophisticated, integrated approach to transmission and generation planning. Serious consideration should also be given to private or part-private models for grid development to reduce the financing burden on EGAT.

Thailand Power Generation by Source (billion kWh, 2014-2023)



Thailand Power Generation Mix (2023)



Grid Readiness Data - Thailand

Power Sector Transition

Share of RE in power generation (%)	23.00%
Share of VRE in power generation (%)	4.48%
Annual growth in VRE penetration (average % over 5 years)	4.36%
MW of VRE in connection queue	N/A
Annual growth in electricity demand (average % over 5 years)	2.49%
Demand projection vs generation supply target (2030) (TWh)	Demand: 282.4 TWh Generation: 259.3 TWh
Independent regulatory body	Yes

Grid Development

Transmission circuit length (km)	40125 km (2025)
Annual growth in transmission expansion, kms (average % over 5 years)	2.65%
Transmission transformer capacity (MVA)	147574 MVA (2025)
Interconnections with neighbouring countries	Yes
Current interconnections capacity (MW)	Grid-to-grid: Thailand - Lao PDR 955 MW Thailand - Cambodia 250 MW Thailand - Malaysia 380 MW
Private participation/ investment in transmission	No

Consumer/ demand-side

SAIFI & SAIDI	SAIFI:0.72 SAIDI:0.38
Cost-reflective tariffs	No
Electricity access (% of population, 2022)	100%
Environmental and Social impact Assessment (ESIA) process for transmission grid projects (Y/N)	Yes
Established public consultation / compensation framework and procedure for transmission projects (Y/N)	Yes

Distribution

Distribution loss (%)	7.36%
Distribution circuit length (km)	N/A
Annual growth in distribution expansion (average & over 5 years)	N/A
Distribution transformer capacity (MVA)	N/A

Grid Operation

RE curtailment rate (%)	N/A
Grid losses (%)	6.8%
System Flexibility (WEF 2024 indicator, 0-100)	76.00
RE Priority dispatch	Yes
Economic grid tariff determination	No

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